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Latest Trends in Finite Element Analysis

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ABSTRACT

This paper highlights the advances in computer graphics and the computational power of the processors which have promoted a method of analysis, applicable to almost all the fields of engineering. The advantages of the computers have been judiciously used in the design of algorithms, based on the principles of finite difference, finite element, boundary element, etc., intended for the analysis of engineering components. The concept of finite element method which has been generalised with the availability of commercial software, is also reviewed with a special emphasis on the future trends. The modelling and visualisation techniques have also been discussed with an inner perspective on the future of visual display of multidimensional complex information. The application of these techniques in some fields is also indicated.

1. INTRODUCTION

The powerful performance of today's computer systems allows the user to handle the toughest of technical, commercial, scientific and business-critical applications with an ability to enhance today's cost-effective applications and handle the most demanding future applications. These capabilities form the basis for the analysis of engineering components, based on the finite element (FE) technique. This technique is a numerical procedure for analysing structures and continua. The system to be analysed is represented by a mathematical model consisting of discrete regions (elements) connected at a finite number of points (nodes). The primary unknowns in an analysis are the degrees of freedoms (DOFs) for each node in the FE model. Corresponding to the DOFs, stiffness, mass and damping matrices as appropriate for each element in the model are generated. These matrices are then assembled to form sets of simultaneous algebraic equations that are solved on a digital computer. The following sections discuss the underlying principles for modelling and analysis. A comment on the unstructured future of the FE techniques is also made.

2. GRAPHIC INTERFACES

A balanced blend of graphics and computational power makes the present day workstations unique and exclusive for applications in the field of mechanical engineering. Through the use of dedicated graphic processors these workstations perform graphical computations in parallel with the CPU. The capabilities of graphic engines, available in the market today include such features as drawing 3,300 pixels per second; 2,19,000 three-dimensional (3-D) vectors per second; 40,000 triangles per second, or 29,000 polygons per second. The resolutions offered are of the order of 1280 × 1024 pixels or even 2048 × 1530 pixels and with a simultaneous display of up to 256 colours. Professional CAD users generally prefer 19" non-interlaced monitors which provide a sharp picture. Non-interlaced displays have a lower scan rate and use long persistance phosphorus to generate flicker-free images. For exceptionally demanding applications where more power is required, options such as the turbo graphics, built using VLSI technology are also readily available.

Users of 3-D applications, such as solid modelling and structural analysis generally require the most

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powerful graphic cards, as the boards for these applications must be able to calculate the areas of polygonal surface for shading.

3. MODELLING

When the space structures were first employed during the 1960s, long and laborious mathematical computations essential to create them had to be done manually. This process of data generation for such complex structural systems was strenuously difficult. The problem, however, stimulated the search for better methods of generating the information required to create suitable space system.

With the concurrent development of the computer, the research in this field shifted towards developing new mathematical algorithms and a suitable computer operating system. The creation of structures of every conceivable design, from single to multilayer grids, is very much simplified using present day software algorithms.

Most of these modellers can be used to generate input data for structural analysis programs. The information provided by the formulation can also be used to visualise the configuration on the screen or through a printout. Once a configuration is generated, it can be further manipulated to reflect the changing requirements that take place during the design process. The possibility of transforming the reference system from a Cartesian reference to a cylindrical or a spherical one, ensures changing a plane configuration into a curved surface of either cylindrical or spherical configuration. Such a transformation may be simply achieved through standard equations that relate Cartesian and cylindrical/spherical coordinates. The parameters in this geometric transformation may be varied to obtain cylindrical surfaces with different radii of curvature.

In the FE modelling process, the principal bottleneck continues to be the generation of the FE mesh. This problem has been somewhat ameliorated with the introduction of fully automatic mesh generators. Conventional approaches to automatic meshing of a continuum requires a solid model, i.e., a geometric representation that can ascertain if a point in space is inside, outside or on the object. Several classical methods generate solid models, including constructive solid geometry (CSG) and boundary representation (*B*-rep) approaches.

With CSG, objects are constructed and stored as combinations of basic 3-D shapes, such as cubes, cylinders or spheres. The shapes are put together using the Boolean operations union, difference and intersection. The applications of such programs include generating models for flow analysis, FE analysis or even for generating engineering drawings.

In addition to CSG, present day software use *B*-rep techniques to maintain accurate information about the surfaces of any object. Though the systems that use *B*-rep were found to create solids with accurate surfaces, they were unable to represent the interiors of the shapes. Hence, the ability of these systems to create valid solids and important engineering displays was significantly limited. Use of CSG and *B*-rep in concert ensures that the shapes created are both valid and complete.

Even in the presence of a solid modeller there still are barriers that must be overcome. First, manufactured parts may not be the same as the designed definition due to tolerances, material shrinkage, warpage, etc. Second, in many cases the lead time to perform the requisite 3-D analysis is so long that the component may have already been manufactured. These scenarios point to a dramatic need for rapid turnaround of analysis of the physical component, which is primarily governed by the time taken for accurate modelling of the component. Researchers at General Electric Co.[1], have developed algorithms which automatically convert computed tomography (CT) data into FE models. The work is based on creating a digital replica that operates on discrete spatial data, and then performing a fully automatic mesh generation. This technique has been extensively used for medical diagnostics and for *X*-ray inspection of industrial components.

Future trends in the display model involve the application of various 3-D graphics and scientific visualisation techniques on a desktop system to understand behaviour that is not clear from numerical results alone. The term scientific visualisation is generally associated with the visual display of multidimensional, time-dependent or complex information. A new concept of stereo display allows the engineers to communidate volume and depth through the use of two eyes. Improved computer monitors, new liquid crystal lenses that allow 3-D viewing, and imaging software to drive the displays, are spurring new applications. The adaptation of this technique for mechanical engineering applications is at a preliminary stage.

4. ANALYSIS

After a model is built in the pre-processing stage, it is analysed for the specified solution sequence. In the analysis phase, the user specifies the type of analysis options, load data, and load step options that initiate the FE solution. The general categories of analysis using the FE technique[2] include structural, thermal, magnetic and electric fields, fluid and coupled-field analysis. The solution generally deals with solving the governing equations to compute the results for the selected analysis type.

The model data is formulated into matrix equations that are suitable for analysis using the FE method (FEM) through the use of proven numerical techniques. The solution sequences use either the Frontal solver or the Jacobi conjugate gradient equation solver. Most of the commercially available software are extremely powerful and easy to use. They also provide a graphics-based menu system which allows interactive data input.

5. FUTURE DIRECTION

The analysis routines being developed include efficient algorithms for optimisation, fluid-structure interaction, coupled-field analysis, CFD, etc. The principles of some of these applications are briefly indicated here.

In optimisation, the goal is to minimise an objective, such as weight or peak stress, subject to constraints on strength. Optimisation problems are placed in three categories : sizing, shape and topology. Sizing relates to determining values of design parameters, such as thickness, cross-sectional area and inertia. Shape optimisation relates to determining the outline of the component and dimensions, such as the radius of a fillet or hole. Topology addresses the basic question of where material should or should not be.

A new technique known as the boundary element method (BEM) is becoming popular in the analysis of complex 3-D solid components, where it is difficult for users to build FE models. Under the BEM, only the boundary of the problem domain is discretised, which reduces the dimensionality by one. Thus, 3-D volume problems are solved as 2-D surface problems and area problems are modelled as 1-D edges. This reduction in the dimensionality results in fewer equations being solved. BEM gives good results when applied to problems in the field of linear heat transfer, linear 3-D elasticity, fracture mechanics, etc. It does not perform well with frame-type structures, nonlinear problems or even for modelling thin shell structures.

Though FE algorithms face a new challenge from formulations as discussed above, they have been successfully used even in the field of biomechanics[3]. The irregular geometry of the human anatomy and the impossibility of conducting experiments on human beings make the FE technique a valuable tool to solve large and complex problems. Three-dimensional models, using eight-noded isoparametric solid elements with orthotropic material properties, of the tibia, knee and prosthesis were analysed for peak joint forces in a normal walking cycle. These techniques are also being used in the design of artificial joints that simulate bone and do not require cement.

6. CONCLUSION

The varied applications of FE methods prove that this technique is of great value as it provides a means with which efficient designs for large, complex problems can be arrived at, which may not be easy by the conventional method.

It can also be deduced that a study of coupling BEM and the FEM codes can lead to more accurate models and hence accurate solutions. The interaction of linear and nonlinear problems is an area where both FEM and BEM can be brought together. However, this field remains a nascent and vital area, with much work remaining to be done.

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